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**ENERGY**

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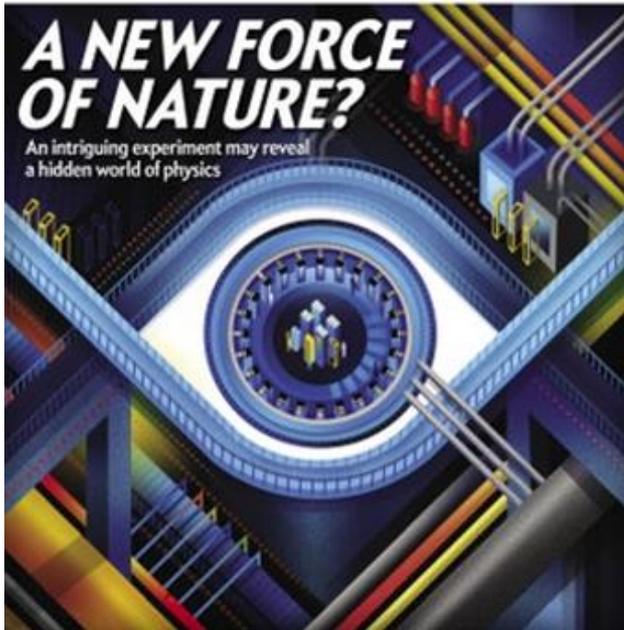
# **DOE HEP Status Update to the National Academy of Sciences Board on Physics and Astronomy**

**Glen Crawford**

**Director, Research and Technology R&D**

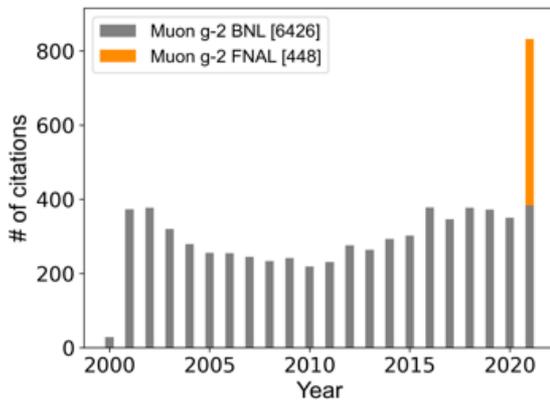
**DOE Office of High Energy Physics**

**April 27 2022**



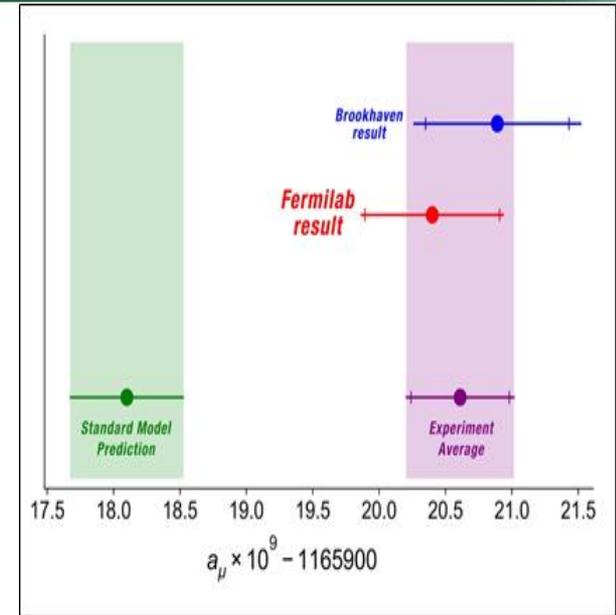
# Science Highlight: Muon g-2 Result

- The first results released April 2021
- The result of Muon g-2 confirmed previous result from Brookhaven experiment
- Four simultaneous publications submitted
  - PRL (g-2), PRD (muon precession frequency), PRA (magnetic field), and PR-AB (beam dynamics)
- The announcement has had a wide reach including 448 citations so far, and an invited lecture by the Nobel Committee for Physics



# Muon g-2 Results and Broader Context

- Fermilab's Muon g-2 experiment measures to 460 ppb released April 2021
  - Combined results from Fermilab and Brookhaven show a difference with theory at 4.2 sigma
  - Results reported are from 6% (Run-1) of total planned data
- Shaping up as the Century of Quantum in physical sciences!
  - Emerging ability to probe and manipulate basic systems “as they are”
  - Muon g-2 is outstanding example of probing the quantum properties of “empty space”
    - ▶ Ability to probe quantum systems at their most fundamental level goes hand in hand with advancing our ability to manipulate quantum systems – in this sense Muon g-2 and QIS are two sides of the same coin
    - ▶ Future of ultra-high sensitivity laboratory measurements like Muon g-2 has very large overlap with advances in quantum technology
      - ▶ Next-generation electric dipole moment experiments (a currently unobserved relative of the magnetic moment), and a variety of experiments looking for wavelike dark matter
    - ▶ Challenges of following up emerging discovery from Muon g-2 will lead to new HEP experiments, which will act as powerful drivers of quantum and other technology advances



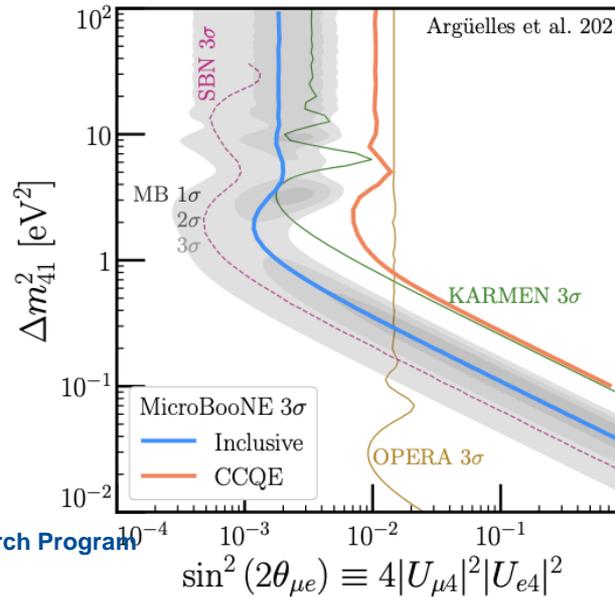
# MicroBooNE Neutrino Highlights

MicroBooNE made a big splash with its recent flagship results:

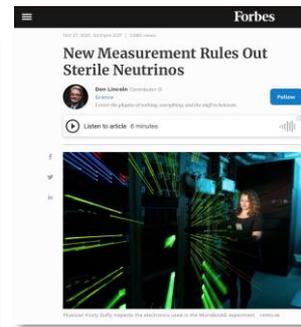
- Liquid argon technology works extremely well, very good news for DUNE
- Disfavors the simplest sterile neutrino explanation of the MiniBooNE excess
- Also disfavors that the MiniBooNE excess was from mis-estimated production of photons

**Need results from the full SBN program to unravel this continuing mystery**

Joe Lykken | Fermilab Research Program



BBC News  
Oct. 27, 2021



Forbes  
Oct. 27, 2021



Newsweek  
Oct. 28, 2021



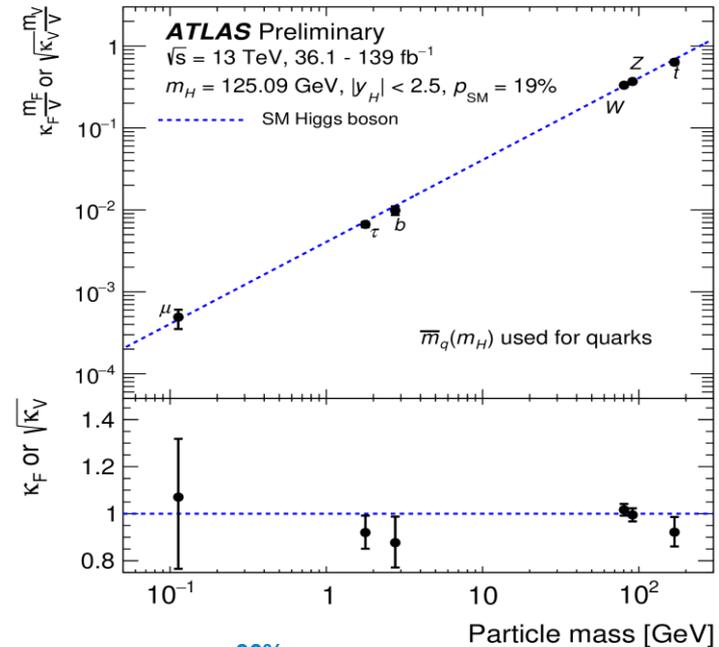
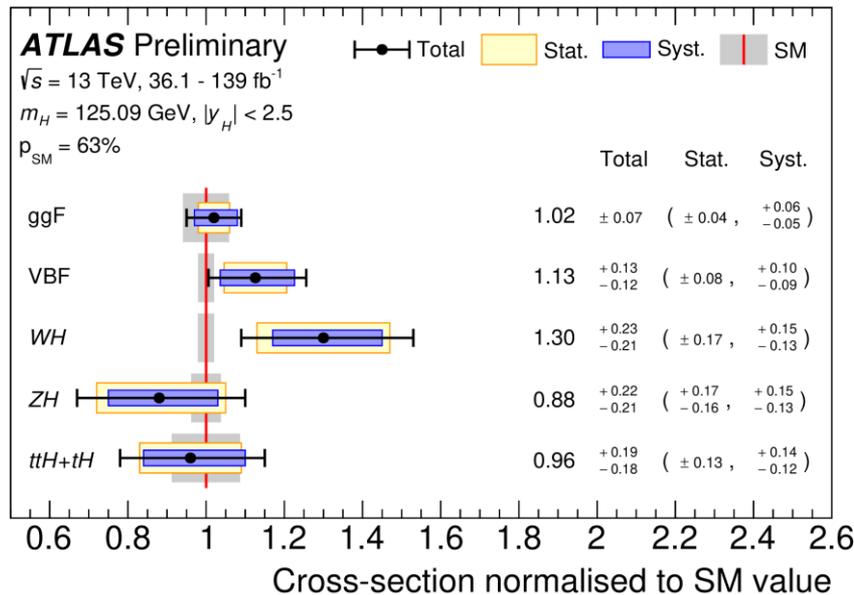
# ATLAS: Higgs Boson Couplings

- Based on the complete LHC Run 2 data set
- Global fit: signal strength  $\mu = 1.06 \pm 0.06$



Coupling measurements ( $B_1 = B_u = 0$ )

$\kappa_\gamma = 1.04 \pm 0.06$ ,  $\kappa_g = 0.92$ ,  $\kappa_{Z\gamma} = 1.37$



$\kappa_\mu < 30\%$

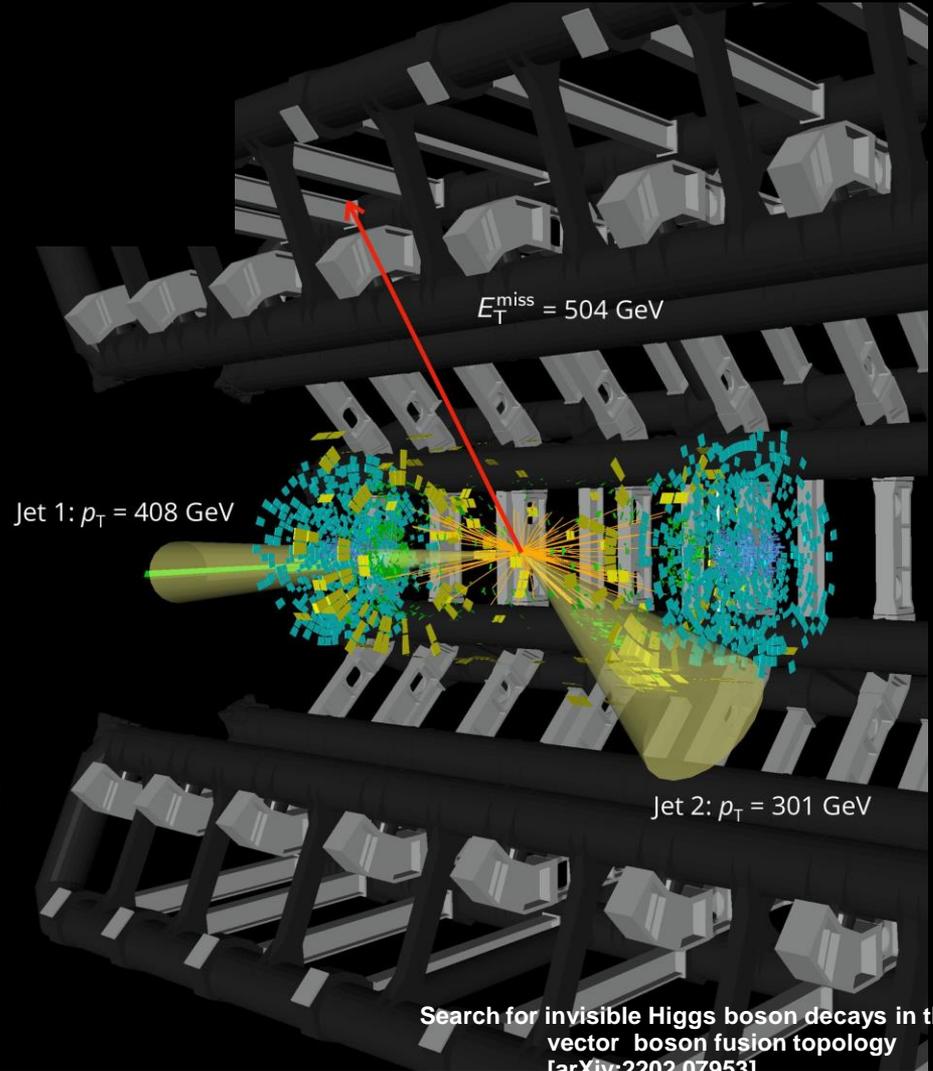
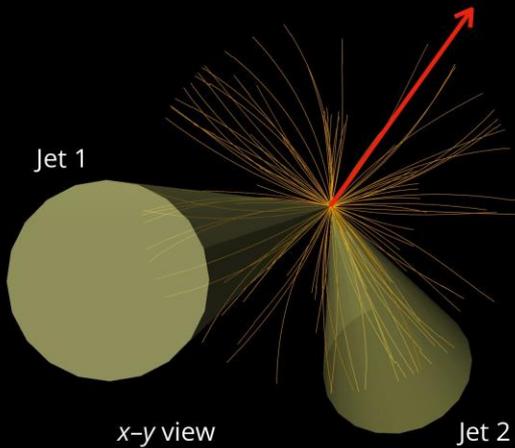
$\kappa_\tau = 7\%$   $\kappa_b = 11\%$   $\kappa_t = 6\%$   $\kappa_{W,Z} = 6\%$

Yet unattained precision on Higgs boson couplings

# Invisible Higgs Searches



$m_{jj} = 2.5 \text{ TeV}$   
 $\Delta\eta_{jj} = 4.0$   
 $\Delta\phi_{jj} = 1.6$



# “The Higgs Boson Turns 10” Nature Paper

Celebrations for the Higgs turning 10 years in 2022: CERN foresee a celebratory event at CERN.



News › News › Topic: At CERN

[Voir en français](#)

## Higgs@10 – save the date!

On 4 July 2012, half a century’s wait came to an end as the ATLAS and CMS experiments announced the discovery of the Higgs boson. Ten years on, we mark the occasion and look forward to a bright future for Higgs research.

6 APRIL, 2022



**ATLAS and CMS will take the opportunity to publish celebratory papers in Nature, with the latest greatest combination from LHC Run 2 data taking**

**The papers have been submitted simultaneously to Nature on March 21, 2022. Paper’s content is kept confidential until July 4<sup>th</sup>; will not yet submitted to ArXiv.**



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# Microelectronics Co-Design Research: “Hybrid Cryogenic Detector Architectures for Sensing and Edge Computing”

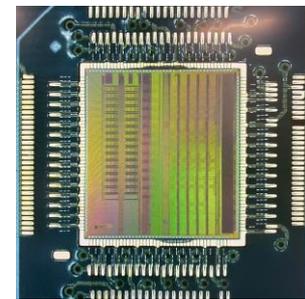
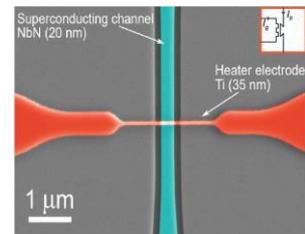
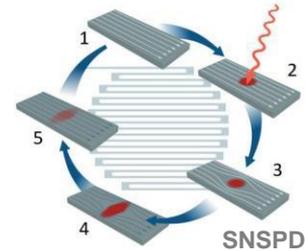
As part of the DOE/SC initiative in Microelectronics, HEP is supporting new innovative R&D efforts in this technology that could have significant impact in particle physics and beyond:

Advancement of two complementary classes of cryogenic state-of-the-art single-photon and particle detectors:

- the Skipper CCD-in-CMOS silicon detector
- a novel hybrid detector platform based on superconducting nanowires

Development and co-design of:

- advanced fabrication and integration techniques
- novel optimized hybrid readout architectures
- cryo-ASICs and cryotron-based superconducting electronics for integrated sensing and data reduction at source, through feature extraction and edge computing.



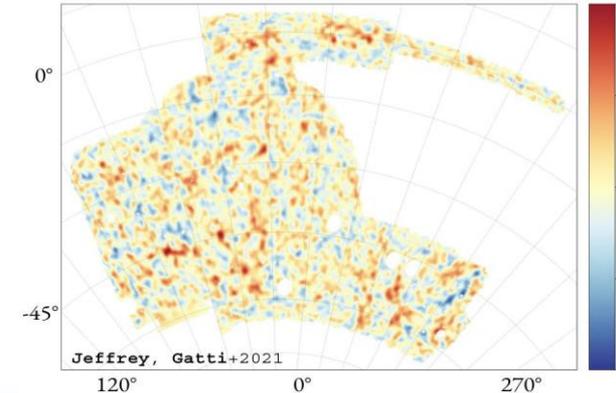
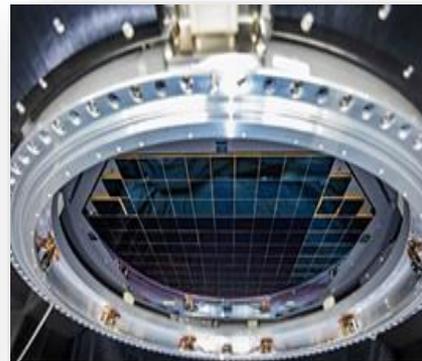
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# HEP Cosmic Frontier: Cosmic Acceleration

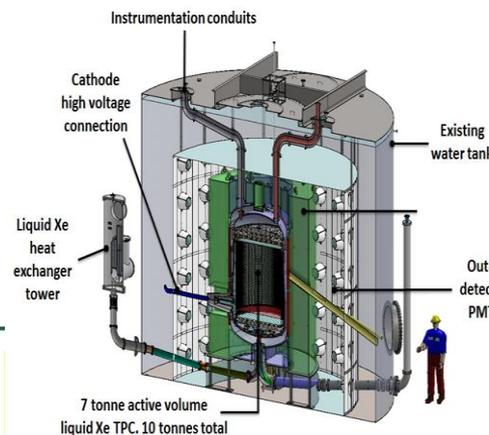
## Dark Energy

- DES Public Release of Year 1-3 “Gold” Cosmology catalogs (Jan.2022). DES’ Y1-3 Weak Lensing mass map is largest to date, with significant improvements over DES Y1 results.
- DESI continues excellent survey operations & has recorded > 10 million spectra; ahead of schedule!
- Rubin Observatory: LSST Camera fabrication complete. Commissioning & facility operations planning underway. The Dark Energy Science Collaboration (DESC) Data Challenge 2 simulations are being used for Rubin Data Preview 0.



# HEP Cosmic Frontier: Dark Matter

- Suite of 3 “gen-2” direct detection search experiments following the 2014 P5 recommendation; variety of particle types over a wide mass range.
- ADMX-G2 2021 results are 5-orders of magnitude better than previous limits, ruling out axion DM hypothesis in this mass-coupling range; continues operations & planned upgrades to search next range
- LZ operates a mile underground in S. Dakota to search for WIMPs using liquid Xenon detector; Commissioning complete late 2021
- SuperCDMS SNOLAB Solid-state WIMP search detector Creighton nickel mine in Canada (HEP+NSF). Fabrication and partial operations in 2023; full operations in 2024.
- Dark Matter New Initiatives: 6 small project concepts being developed for dark matter searches in new areas of phase space and with new technologies.



**ADMX**  
AXION DARK MATTER EXPERIMENT

**SUPER  
CDMS**  
Cryogenic Dark Matter Search

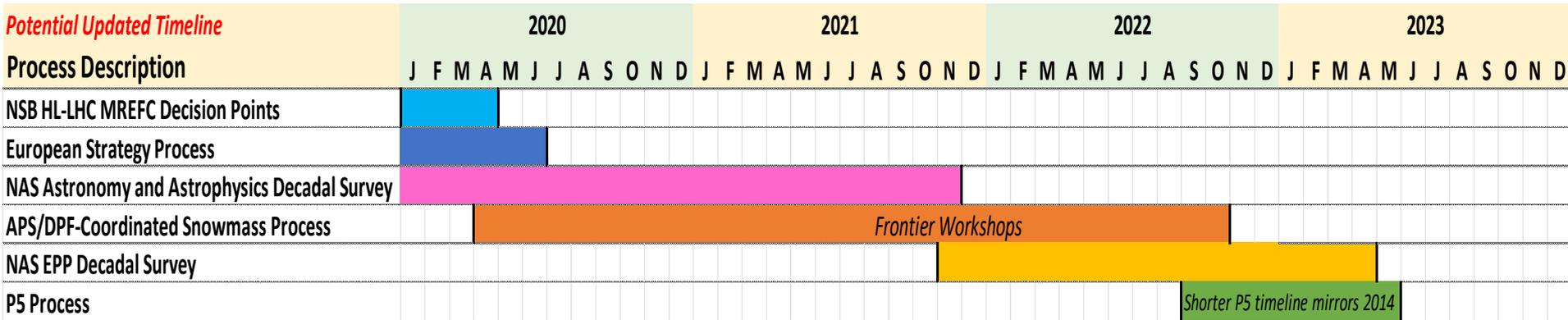


# PIP II CD Status

- CD-2/3 for the Early Conventional Facilities Subproject was approved by the Director of the Office of Science on July 17, 2020.
  - The cryogenics building is nearly complete, but the electrical switchgear is delayed.
- CD-2 was approved by the Director of the Office of Science on December 14, 2020.
- CD-3A was approved by the Associate Director for High Energy Physics on March 16, 2021, for \$12.5 million.
- The project has been working through its design reviews with a tailored plan that will be presented to you.
  - Progress against the plan has been excellent.



# Snowmass/P5 timeline



HEP community-wide “Snowmass” study process organized by the Division of Particles and Fields (DPF) of the American Physical Society (APS) has restarted.

New National Academy of Sciences (NAS) Elementary Particle Physics (EPP) Decadal Survey will run concurrently with and complement the community-driven Snowmass process.

Next P5 process to begin after Snowmass, circa late 2022: P5 report by May 2023 will inform FY 2024 Congressional actions & FY 2025 U.S. budget formulation

# EPP 2020 Charge (revised)

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National Academies of Sciences, Engineering, and Medicine will convene a committee to perform a decadal survey addressing the following:

*Assess the current scientific status and prospects of the field of particle physics, noting significant recent scientific and technical achievements, with connections to other scientific areas where appropriate. Identify the most compelling science challenges and frontiers in elementary particle physics through a series of fundamental questions that could motivate research in the next decade and beyond, irrespective of the tools and techniques to address them.*

*Distinguish which of these questions may be addressed with available experimental tools in the coming decade and which need new techniques or approaches. Survey promising technical research areas that may provide new particle physics tools enabling new approaches to explore these fundamental questions.*

# Background : International Benchmarking

- A recent BESAC report on international benchmarking of scientific resources and capabilities was viewed as a successful exercise that examined the U.S. Basic Energy Sciences program in a global context
- This report identified critical research areas where competition from other major players in the international community may threaten to eclipse U.S. scientific and technological leadership, and recommended strategies to address these challenges.
- DOE and NSF have developed a charge for HEPAP which addresses similar issues for the particle physics program that takes account the very different international context of this program.

## CAN THE U.S. COMPETE *in Basic Energy Sciences?*

CRITICAL RESEARCH FRONTIERS AND STRATEGIES

A report by the BESAC Subcommittee on International Benchmarking



# FY 2023 Budget Highlights - HEP

- **FY 2023 Request for ~\$1,122M** focuses resources towards the highest priorities in fundamental research, operation and maintenance of scientific user facilities, facility upgrades, and projects identified in the 2014 Particle Physics Project Prioritization Panel (P5) report.
- Experimental Science and Technology R&D is “mission-driven”:
- Develops and supports a specific portfolio of projects. **Emphasis is placed on supporting science collaborations in all stages, conducting experiments, and seeking the best possible science results.**
- Makes **significant, coherent contributions to facilities & experiments** selected for the program, including project management
- Supports **R&D that will advance the state-of-the-art in particle accelerators & detectors**, which will lead to new, more capable facilities.
- Supports **R&D to enable new and transformative capabilities in QIS, AI/ML**, and crosscutting technology areas.
- Theory supports activities that **provide the vision** and the mathematical framework for understanding and **extending our knowledge** of particles, forces, space-time, and the universe.
- **HEP supports ~85% of U.S. particle physics (in \$)**, including **~all national labs**.



Main Injector at the Fermilab Accelerator Complex



Short-Baseline Neutrino Detector at Fermi National Accelerator Laboratory



LZ direct dark matter search experiment at SURF

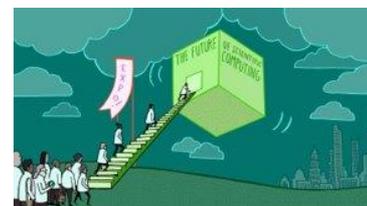
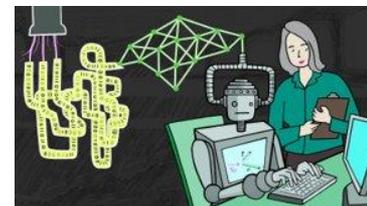


CMS Detector at LHC in CERN



# FY 2023 Budget Highlights - HEP Research

- Research funding includes an increase of \$2.04M or 0.5% over FY 2022 Enacted, with increases targeted to Administration priorities (+\$6.8M).
  - Core Research activities decrease (-\$4.7M)
- Artificial Intelligence/Machine Learning (\$40.0M) to tackle the challenges of managing increasingly high volumes & complexity of HEP data
- Advanced Computing (\$5.2M) to ensure broad access to exascale computing resources to HEP researchers via the internet and remote virtual platforms.
- Quantum Information Science (\$25.6M) to co-develop quantum information, theory, and technology with core research activities, and to pursue new capabilities in sensing, simulation, and computing.
- Superconducting Quantum Materials and Systems (SQMS) QIS Research Center (\$25M) to promote basic research and early-stage development to accelerate the advancement of QIS through vertical integration between systems and theory, hardware, and software.



# HEP - FY 2023 President's Request

## (Dollars in thousands)

	FY 2021 Enacted	FY 2022 Enacted	FY 2023 Request	FY 2023 Request vs FY 2022 Enacted	FY 2023 Request vs FY 2021 Enacted
<b>High Energy Physics</b>					
Energy Frontier, Research	68,000	71,833	70,833	-1,000 -1.39%	2,833 4.17%
Energy Frontier, Facility Operations and Experimental Support	53,650	49,850	48,787	-1,063 -2.13%	-4,863 -9.06%
Energy Frontier, Projects	72,500	65,000	85,000	20,000 30.77%	12,500 17.24%
<b>Energy Frontier Experimental Physics</b>	<b>194,150</b>	<b>186,683</b>	<b>204,620</b>	<b>17,937 9.61%</b>	<b>10,470 5.39%</b>
Intensity Frontier, Research	63,082	65,994	67,644	1,650 2.50%	4,562 7.23%
Intensity Frontier, Facility Operations and Experimental Support	166,785	161,845	172,261	10,416 6.44%	5,476 3.28%
Intensity Frontier, Projects	3,000	15,000	6,000	-9,000 -60.00%	3,000 100.00%
<b>Intensity Frontier Experimental Physics</b>	<b>232,867</b>	<b>242,839</b>	<b>245,905</b>	<b>3,066 1.26%</b>	<b>13,038 5.60%</b>
Cosmic Frontier, Research	47,091	46,012	48,512	2,500 5.43%	1,421 3.02%
Cosmic Frontier, Facility Operations and Experimental Support	44,500	38,500	47,590	9,090 23.61%	3,090 6.94%
Cosmic Frontier, Projects	6,000	23,000	1,000	-22,000 -95.65%	-5,000 -83.33%
<b>Cosmic Frontier Experimental Physics</b>	<b>97,591</b>	<b>107,512</b>	<b>97,102</b>	<b>-10,410 -9.68%</b>	<b>-489 -0.50%</b>
Theoretical, Computational, and Interdisciplinary Physics, Research	136,362	157,422	163,746	6,324 4.02%	27,384 20.08%
<b>Theoretical, Computational, and Interdisciplinary Physics</b>	<b>136,362</b>	<b>157,422</b>	<b>163,746</b>	<b>6,324 4.02%</b>	<b>27,384 20.08%</b>



# HEP - FY 2023 President's Request (cont ...)

*(Dollars in thousands)*

	FY 2021 Enacted	FY 2022 Enacted	FY 2023 Request	FY 2023 Request vs FY 2022 Enacted	FY 2023 Request vs FY 2021 Enacted
<b>High Energy Physics</b>					
Advanced Technology R&D, Research	72,833	75,344	67,911	-7,433	-9.87%
Advanced Technology R&D, Facility Operations and Experimental Support	43,262	40,200	44,736	4,536	11.28%
<b>Advanced Technology R&amp;D</b>	<b>116,095</b>	<b>115,544</b>	<b>112,647</b>	<b>-2,897</b>	<b>-2.51%</b>
HEP Accelerator Stewardship, Research	10,835	...	...	...	...
HEP Accelerator Stewardship, Facility Operations and Experimental Support	6,100	...	...	...	...
<b>HEP Accelerator Stewardship</b>	<b>16,935</b>	<b>...</b>	<b>...</b>	<b>...</b>	<b>...</b>
<b>Program Subtotal</b>	<b>794,000</b>	<b>810,000</b>	<b>824,020</b>	<b>14,020</b>	<b>1.73%</b>
<b>18-SC-42 Proton Improvement Plan II (PIP-II), FNAL</b>	<b>79,000</b>	<b>90,000</b>	<b>120,000</b>	<b>30,000</b>	<b>33.33%</b>
<b>11-SC-40 LBNF/DUNE, FNAL</b>	<b>171,000</b>	<b>176,000</b>	<b>176,000</b>	<b>...</b>	<b>...</b>
<b>11-SC-41 Muon to Electron Conversion Experiment, FNAL</b>	<b>2,000</b>	<b>2,000</b>	<b>2,000</b>	<b>...</b>	<b>...</b>
<b>Construction Subtotal</b>	<b>252,000</b>	<b>268,000</b>	<b>298,000</b>	<b>30,000</b>	<b>11.19%</b>
<b>Total High Energy Physics</b>	<b>1,046,000</b>	<b>1,078,000</b>	<b>1,122,020</b>	<b>44,020</b>	<b>4.08%</b>



# FY22 Initiative : HEP Advanced Computing

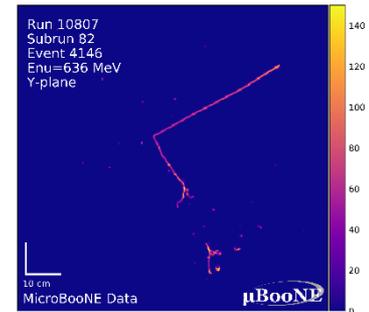
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- The Office of Science aims to develop the computing infrastructure necessary to support future scientific discoveries by identifying computing needs common across programs and the infrastructure necessary to support them
- The Office of High Energy Physics will support the SC Advanced Computing Initiative with new activities across four HEP Programs
  - Energy Frontier – work to develop expanded HPC usage for LHC experiments. This work continues to push high throughput computing workflows onto DOE SC HPCs.
  - Intensity Frontier – work to develop HPC applications for DUNE, the Short Baseline Neutrino program, and Liquid Argon TPCs using high throughput computing workflows.
  - General Accelerator R&D – work to develop scheduling across DOE SC User Facilities to coordinate experiment data taking and HPC computing time to process experimental data in real-time using HPCs.
  - Theory – work to expand use of HPCs for high order correction calculations for perturbative QCD. These complex simulations are needed to both produce simulations of sufficiently fidelity to compare with data and address some of the High Luminosity LHC computing simulation needs.
- These new activities have significant relevance to work in other SC offices
  - Common interest with ASCR, BES, FES, and NP

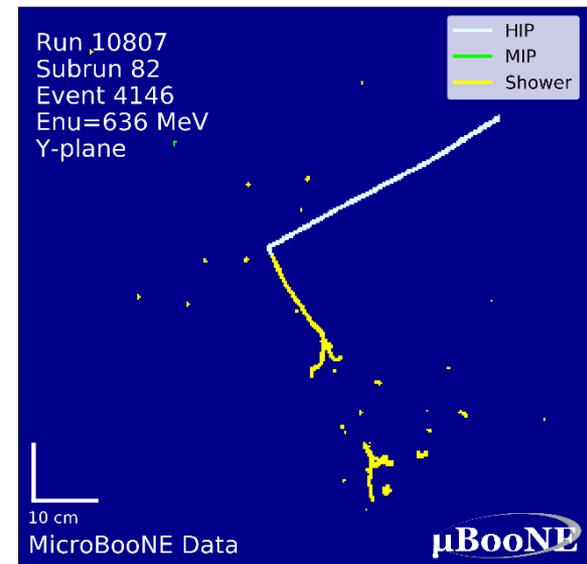


# Artificial Intelligence & Machine Learning

- The President has placed a high priority on ensuring continued U.S. leadership in AI research and development
  - Lead the world in the development of trustworthy AI and prepare the future U.S. workforce for the integration of AI systems across all sectors of economy and society.
  - Launched the [AI for Science Initiative](#) to support these goals in FY20
- Broad interest in AI is being driven by the accumulation of large datasets and growing computational capacity for processing
  - Machine Learning (ML) is included when appropriate as tool to derive insights from these large datasets
- HEP has a long track record of successful AI/ML research and development across many experiments and decades
  - One recent example is the Deep Learning low energy excess analysis by MicroBooNE
    - Using semantic segmentation to identify the detector hits caused by protons, muons, or electrons based on the unique signatures left in the detector.



Raw Detector Hit



Deep Learning Prediction



# Current HEP AI/ML Program

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- In recognition of HEP's history in AI/ML research, activities are supported through two paths:
  - Programmatic AI/ML – integrated/embedded in the frontier programs. Applications of primarily ML techniques to improve HEP results within a given frontier.
    - Supported through the University and Lab comparative review process
  - Core AI/ML – research into AI/ML topics from an HEP perspective and blue-sky R&D necessary to enable future HEP breakthroughs across frontiers
- Snapshot of Core AI/ML programs:
  - Early Career Awards across HEP frontiers with significant AI/ML component
  - Machine Learning Across the Frontiers – Computational HEP program to develop ML applications for HEP
  - Exa.TrkX – Computational HEP program to use Exascale computing to perform track reconstruction for HL-LHC
  - AI for Scientific User Facilities – projects to develop AI systems that can improve online facility operations
  - **Recently launched dedicated AI for HEP FOA ([DE-FOA-0002705](#))**
    - More information on HEP's involvement in the [AI initiative](#)



# Reaching a New Energy Sciences Workforce (RENEW)

FY 2023 \$60M,  $\Delta$ =+\$30M

Building foundations through undergraduate and graduate training opportunities for students and institutions historically underrepresented in the SC research portfolio



- SC conducted outreach and listening sessions in FY 2022 on barriers to participation in SC opportunities to inform FY 2022 FOAs



- **FY 2022 FOAs will pilot models** of support that directly address barriers to participation in SC supported fields of research
- **Models will be evaluated**



- FY 2023 doubles investment and commitment to advance discovery and innovation by increasing the diversity of individuals and institutions supported



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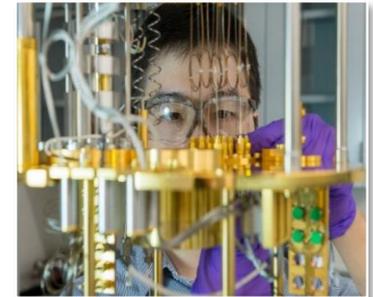
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# Funding to Accelerate Inclusive Research (FAIR)

FY 2023 \$36M

**FAIR will enhance research on clean energy, climate, and related topics at minority serving institutions (MSIs), including underserved and environmental justice regions**

- Builds research capacity, infrastructure, and expertise at MSIs
- Develops mutually beneficial relationships between MSIs and DOE national laboratories and user facilities
- Complements the RENEW initiative (internships at national laboratories for workforce development)
- Provides support of single PI or research teams, and includes an equipment or infrastructure element
- Majority of funds will go directly to HBCUs/MSIs, a portion will fund the partnering institution (Lab, university)





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## SC Diversity, Equity & Inclusion Initiatives



**Dr. Julie Carruthers**

Acting Director, Office of Scientific Workforce Diversity, Equity, and Inclusion;  
Senior Science & Technology Advisor, Office of the Principal Deputy Director

<https://science.osti.gov/sw-dei>

# Increasing Participation in SC Research – Listening Sessions

In December 2020, SC initiated a coordinated approach to increasing participation by individuals and institutions historically underrepresented in SC-sponsored opportunities.

SC launched a series of listening sessions and discussions to seek community input on barriers to participation in SC-sponsored research and input on opportunities for overcoming those barriers – 16 sessions between August – December 2021.

- SC conducted a synthesis of the over 250 comments that were recorded across the sessions; main themes and takeaways from the sessions are aligned with the discussions and feedback from similar public discussions hosted by NASEM and other federal agencies.
- The most frequent comments recorded were in the areas of systemic barriers, lack of awareness of opportunities, implicit bias, solicitation processes, access to equipment, recruitment, promoting DEI, and mentoring.

Listening session input is informing the Program Offices' approaches to the [Reaching a New Energy Sciences Workforce \(RENEW\)](#) initiative. (Scope and processes for solicitations in FY 2022)



# COVID 19 Impacts on Projects

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- COVID has had different impacts on projects depending on the stage of the project.
  - DESI, LZ, LSSTCam, and FACET II were close to completion and were able to finish without rebaselining.
    - On LZ and LSSTcam the KPP were met, but some final work was moved to operations.
  - SuperCDMS-SNOLAB, Mu2e, and HL-LHC Accelerator Upgrade Project are all past CD-3 and had large enough impacts that rebaselining is necessary.
  - PIP II, HL-LHC ATLAS, and HL-LHC had impacts that required additional funds to be added in order to maintain their planned scope.



# Office of Science Ukraine Dear Colleague Letter

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- On April 4, 2022, the Office of Science published a Dear Colleague Letter in support of scientists impacted by the conflict in Ukraine.
  - <https://www.osti.gov/appdata/sc/UkraineDCL.pdf>
- The letter reminds currently-supported university researchers that supplemental funds may be requested to accelerate scientific discovery by hosting or collaborating with students and scientists who have been impacted by the conflict.
- Supplements are intended to be short term (up to one year) and better position students and scientists to help rebuild science programs on return to Ukraine.
- No additional funds have been appropriated by Congress. Requests for supplemental funding compete against all other requests for funding.
- Common questions and answers have been posted online.
  - <https://science.osti.gov/external/ukraine-faq>
- Please contact [SC.DCL@science.doe.gov](mailto:SC.DCL@science.doe.gov) if you have questions.



# FY 2021 HEP Early Career Research Awardees

- Lindsey Bleem, *ANL*
- Chihway Chang, *U. Chicago*
- Netta Engelhardt, *MIT*
- Farah Fahim, *FNAL*
- Philip Harris, *MIT*
- Tongyan Lin, *UC San Diego*
- Xueying Lu, *Northern Illinois U.*
- Brian Nord, *FNAL*
- Simone Pagan Griso, *LBNL*
- Diana Parno, *Carnegie Mellon U.*
- Kiersten Ruisard, *ORNL*
- Daniel Scolnic, *Duke U.*
- Indara Suarez, *Boston U.*
- Caterina Vernieri, *SLAC*
- Hao-Yi Wu, *Boise State U.*





## Summary

- Shaping up to be the century of quantum in particle physics
- HEP is advancing its cutting edge initiatives in Artificial intelligence, machine learning and microelectronics
- HEP is pushing for an effort in diversity and inclusion in such DOE wide initiatives such as RENEW and FAIR

